Gen IV GRNS
April 2-3; Washington, DC

Sustainability Scores

Report From Gen IV Fuel Cycle Crosscut Group (FCCG)

Conclusions: Sustainability Scoring

- *The FCCG Believes the Scoring achieved Acceptable Consistency in Distinguishing Among Fuel Cycle Classes*
  - *Achieved Discrimination among the FCCG Generic Fuel Cycles*
    - *Once-through/partial recycle; full fissile recycle; full actinide recycle*
  - *Where knowledge is lacking: achieved consistency in <u>relative</u> scores for distinguishing fuel cycle classes*
    - *Contribution of "conditioning" to waste mass, waste volume*
    - *Contribution of minor actinides to 500y heat load and toxicity source term*

- *<u>Within</u> a Fuel Cycle Class, Distinctions were Difficult to Score; and Several FCCG Consistency Ground Rules Affected Some Scores*
  - *Coarse Granularity of the SU-1 Metric (30% range of center box)*
  - *<u>All</u> Full recycle is 10X better than top box in SU1 – little distinction*
  - *Thermal reactor Once-through vs MOX-mono vs DUPIC*
    - *Difficult to distinguish by score within a 30% range of the same as Reference Box*

- *Nonproliferation Criteria are currently narrowly focused on Power Plant Link in the Fuel Cycle*
  - *Further developments needed to distinguish among and within fuel cycle classes*

Sustainability Criteria and Metrics

Criterion	Metric Reference	Scale	Granularity
• SU1 Tonnes of U Required/GWe y	150-200	linear	coarse (30% range center to center)

- Fully quantifiable by Formula [Assumes we count lifetime fissions – even with interim storage & even with mono or multi recycle in other reactors]

- Once-Through and Partial Recycle
  - Depends on * enrichment
    * enrichment of tails
    * Ave discharge burnup
    * station conversion efficiency

  - For purpose of Consistency
    * FCCG defined tails enrichment as 0.3%
    * FCCG urged use of Once-Through unless strong case made for MOX or DUPIC

  - Enrichment dependence dominates versus burnup and station efficiency effects
    * Coarseness of Metric Scale: difficult to improve on reference
      : easy to degrade using higher enrichment to increase burnup

Sustainability Criteria and Metrics

- ***SU1: Full Fissile and Full Actinides Recycle***
  - ***Depends on*** **** Number of Recycle Passes (1/atom percent burnup)***
    **** Loss to waste per Pass***
  - ***All Gen-4 Recycle concepts are full actinide recycle; all are ~10X better than top box***
  - ***Coarseness of metric: hard to fall below top box even with large recycle losses or low burnup***

	Reference	Scale	Granularity
• SU2-1 Tonnes of SNF or HLW/GWe y Sent to Waste	15-20	Linear	Coarse (30% range center to center)

- ***Intent of EMG is Tonnes of <u>Conditioned</u> SNF or Tonnes of HLW <u>including diluent</u>***
  - ***Data for many of Generation-4 concepts was not available to TWG's***
- ***For Consistency of <u>relative</u> ratings among concepts***
  - ***FCCG used (Mass of fission products + mass of heavy metal)***
  - ***This surrogate metric is fully quantifiable by formula***
    - ***~ 1 gm/MW_{th}d * 1/η + Heavy Metal Sent to Waste in SNF or Lost in Recycle***
- ***The Numerical SU1 and SU2-1 results were generated by FCCG by formula using TWG input***
  - ***For SU1*** ***Mass of virgin U/GWe y***
  - ***For Su2-1*** ***Mass of (FP+HM) to Waste/GWe y***
  - ***They clearly distinguish recycle from once-through***
  - ***Less clear once-through vs partial recycle***

Sustainability Criteria & Metrics

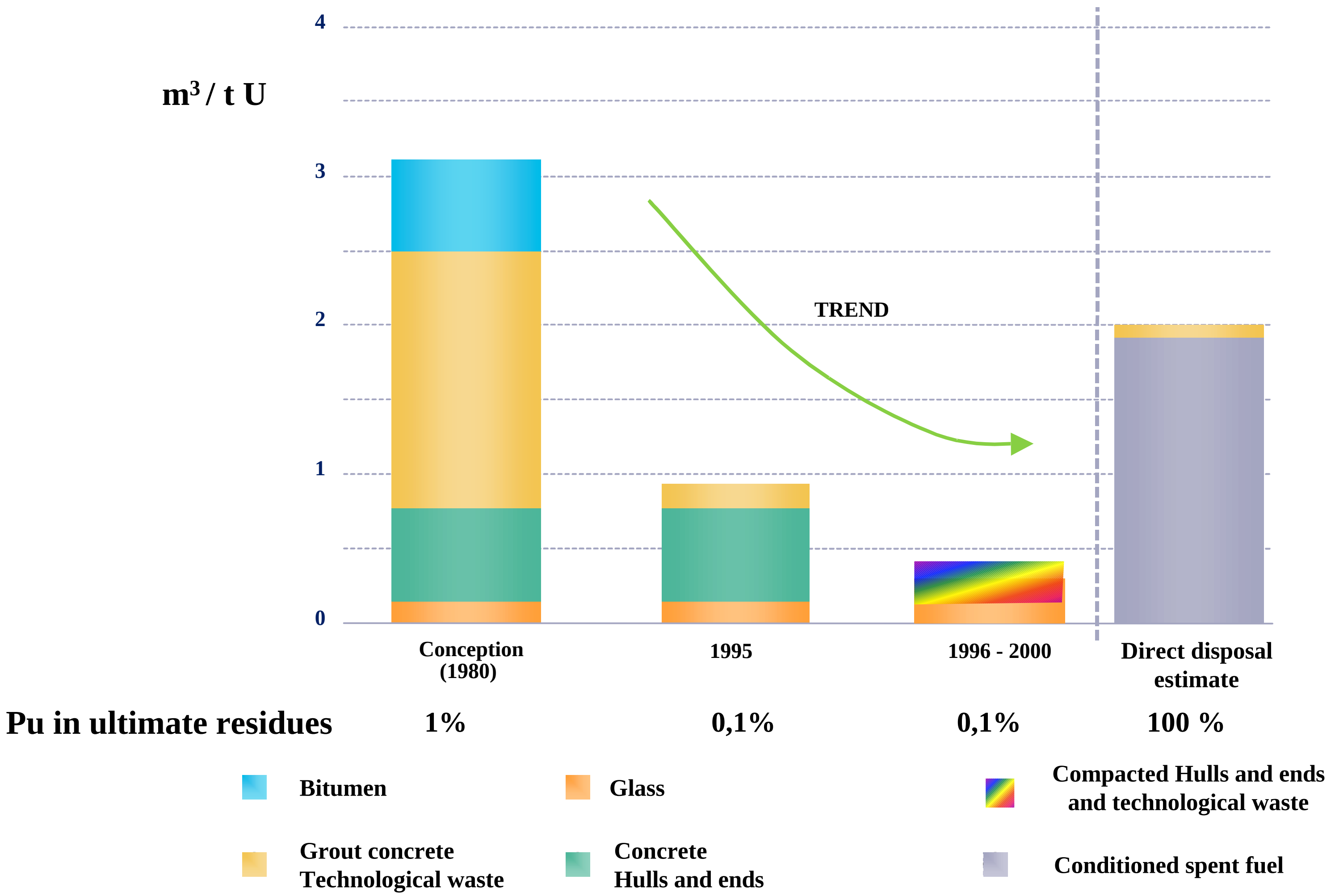
	Reference	Scale	Granularity
• SU2-1 Volume of SNF or HLW	15-20 M^{3}/GWe y	Linear	Coarse (30% range center to center)

- *The intent of EMG is volume of SNF and/or HLW – as conditioned for disposal – but not including any casks*
  - *The data were not available for many of the Generation-4 concepts*

- *To judge the relative consistency of concepts*
  - *The FCCG relied on*
    - *Data from French PUREX HLW production vs SNF*
    - *Data from Triple A studies of Waste Volumes predicted for advanced recycle (on the basis of significant but incomplete waste form development; fabrication; and leach testing and of flow sheet development and bench testing of recycle/refab)*

- *French data from PUREX shown next*

Volumes of final residues conditioned in UP3 (High level and long-lived waste after conditioning)



Sustainability Criteria & Metrics

	Reference	Scale	Granularity
• *SU2-1 (Heat Load in SNF or HLW at 500y/GWe y*	*1-3 kw/GWe y*	*~linear*	*Very coarse (~ 70% center to center)*
Toxicity Source Term in SNF or HLW at 500y per GWe y	*500-1500 MSV/GWe y*	*~log*	*(~75%)*

- ***At 500 y's both Heat load and Toxicity Source Term of SNF***
  - ***Are dominated by the trivial weight fraction of transuranics in the SNF mass***
    - **** i.e., ~ 1.5 w/o Pu + ~0.15 w/o Minor Actinides in SNF***
  - ***The Fission Product Contributions are small by 500y***
    - **** FP dominates heat source at short time (principally Cs, Sr with ~35y half life) but have become secondary to actinides by 500y's***
    - **** FP's dominates toxicity source term at short time but have decayed to below that of actinides by 500y's***

- ***The 500y Heat Load and Toxicity***
  - ***Depend strongly on the (Minor Actinide)/(Total transuranic) mass fraction (Minor actinides heat load and toxicity per unit mass are high)***

Sustainability Criteria & Metrics

- ***To Improve Performance against these criteria***
  - ***a. Send less TRU to waste/GWe y***
  - ***b. Send TRU of smaller minor actinide content to waste/GWe y***

- ***For Once-Through and partial Recycle in Thermal reactors (where SNF goes to waste)***
  - ***The TRU mass/GWe y (and heat load and toxicity source term)***
    - ***Decrease with station efficiency at any given burnup – but not 70 to 75%***
    - ***Increase with burnup – because MA fraction increases***

- ***For Full Fissile or Full Actinide Recycle in Fast Reactors (where only trace losses go to waste)***
  - ***The TRU mass/GWe y sent to waste is reduced vis-à-vis once-through***
  - ***The MA mass/GWe y sent to waste depends on choice of full fissile vs full actinides recycle***

- ***For most Generation-4 concepts, the TWG's had incomplete information***

- ***To check scoring consistency, the FCCG relied on several previous studies (OECD-NEA, Triple A)***
  - ***OECD-NEA result next***

OECD-NEA Study Shows Importance of Minor Actinide Recycle vs Pu Recycle Only

1 Gwe y = 8.76 terrawatt hr

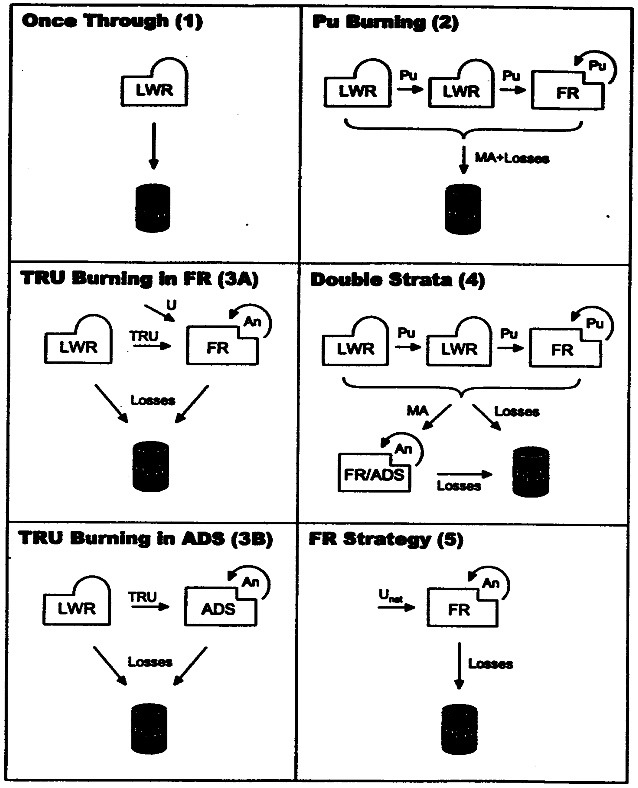


Fig. 1. Nuclear Fuel Cycle Schemes of the OECD-NEA Study

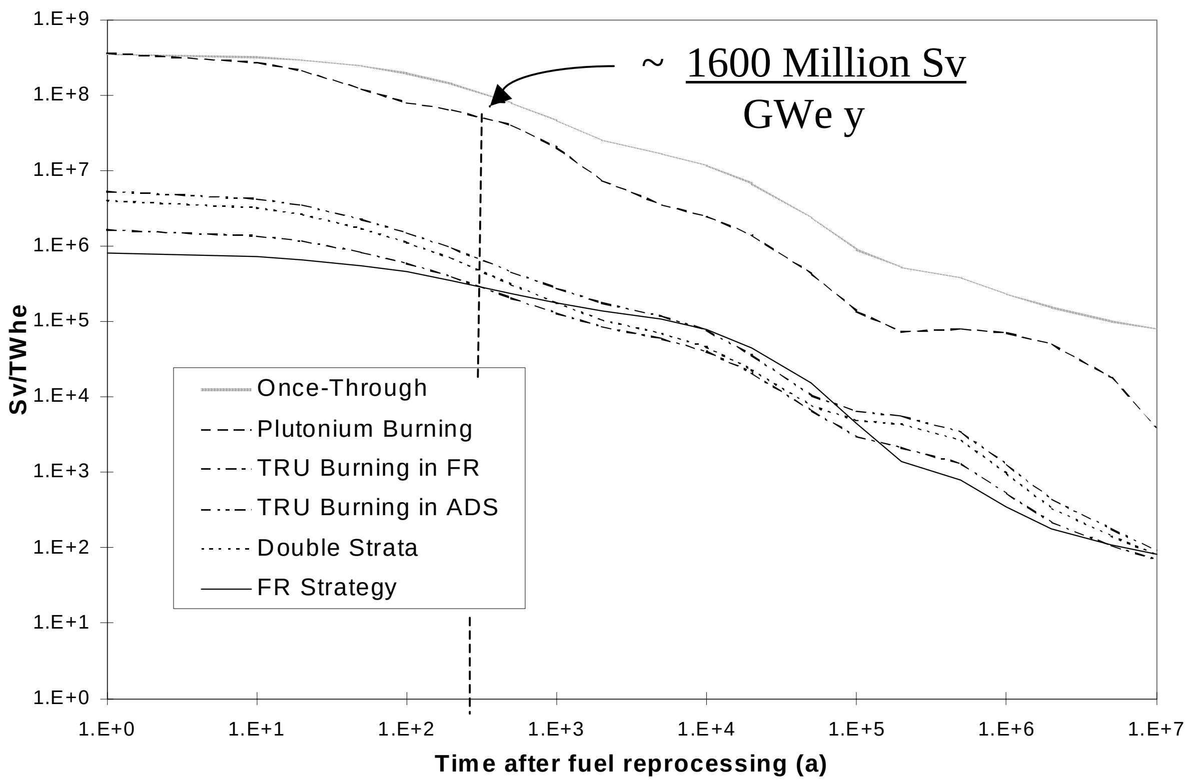


Fig. 2. Evolution of the Actinide Waste Radiotoxicity (Average Burnup of Metal and Nitride Fuel: 150 GWd/t^{HM})

SU2 Summary Observations: Recycle Long Term Toxicity, Heat Load and HLW Waste Volume vs SNF

- *Heat & Toxicity are dominated by a trivial mass fraction of SNF*
  Pu ~ 1.5 w/o
  Ma ~ 0.15 w/o
- *Any fast multi recycle of all TRU puts you in the top box for mass to waste (by ~ factors of 10) – even poor recycle recovery fractions*
- *This will reduce decay heat (long term) by factor of 50 to >100*
  This will reduce toxicity (long term) by factor of 100 to 200

However

- *Multi Recycle of Pu only (and MA go to waste)*
  - *Gains < factor of 10 (not several hundred) on toxicity*
  - *Recycling MA → Remote Fabrication!*
- *Volume of HLW forms from Multi TRU Recycle are factors of 2 to 3 larger than SNF Volume; MOX Mono Recycle <1/2 (but MOX SNF still has to be disposed)*

Sustainability Criteria and Metrics

- ***SU3-1 Avoid Separated Weapons Usable Materials***
  SU3-2 Impede Handling and Recovery of weapons Useable Material
  SU3-3 Reactors Have Passive features That Resist Sabotage

- ***EMG intent***
  - ***Focus on the Power Plant itself***
  - ***Defer a cradle to grave fuel cycle nonproliferation evaluation***
    - ***Until the fuel cycle technologies and facility designs of the leading concepts are better defined***
    - ***Until an evaluation approach for Generation-4 is better defined***

- ***These criteria and metrics are clearly stated; don't require judgments***
  - ***There were no consistency issues here***

- ***Observation for the future extension of Consideration to Cradle to Grave Fuel Cycle***
  - ***Every full recycle concept in Generation-4 employs the same strategies***
    - * ***Full actinide recycle in commixed product streams***
    - * ***Remote refabrication***
    - * ***Send only trace losses of fissile to waste; ~fissile free repository***
    - * ***Reduce enrichment deployments***

  Therefore
  - ***Distinguishing among them will require accounting for cost effectiveness of proliferation resistance as well as technology per se***

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